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REMOVAL OF ALGAL NUTRIENTS FROM RAW
SEWAGE WITH LIME

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TERMINAL REPORT

"REMOVAL OF ALGAL NUTRIENTS FROM
RAW SEWAGE WITH LIME"

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PERIOD COVERING SEPTEMBER 1, 1961
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by

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METCALF & EDDY, ENGINEERS
BOSTON, MASSACHUSETTS

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INTRODUCTION

Domestic sewage and some industrial wastes are rich sources of nitrogen and phosphorus, two essential algal nutrients. Primary and secondary sewage treatment operations do not adequately reduce the concentrations of these elements before discharge and some consideration has been given to tertiary treatment as a means of removing them. It is possible, however, to improve the effectiveness of the primary step and this would be a more satisfactory solution for many cases, in the opinion of the investigators. This was the premise upon which this research was initiated and conducted.

Ecological control of algal growths can be accomplished by limiting the supply of one essential food element. To attempt this by removal of nitrogen from sewage is impractical for many reasons, the most significant one being that certain species of blue-green algae (which are often the most troublesome forms) can thrive in nitrogen-poor environments by fixing nitrogen for their needs from the atmosphere. On the other hand, phosphorus can be removed from sewage readily and it is not replaced in the environment.

This study was undertaken to investigate the treatment of raw sewage with lime as a form of primary treatment. An evaluation of this process, which was in common use a few decades ago, as a means of removing phosphorus was made. Removals of nitrogen, BOD, and coliform bacteria were also measured as well as the character and volume of sludge produced.

A less extensive investigation was also made of two forms of secondary treatment for cases where primary treatment alone would be inadequate.

LABORATORY PROCEDURE

Raw sewage was collected twice weekly at the Ward Street Pumping Station in Boston for seven months, mid-December, 1961, to mid-July, 1962. Raw sewage after degritting and comminution was also collected once a week at the Marlborough, Massachusetts, sewage treatment plant for three months, September through November, 1962. The two sewages were selected as representing extremes in strength, the Marlborough sewage being roughly two to three times as strong as that of Boston. While essentially all of this report is based on these two sewages, single grab samples were taken at four other treatment plants; Clinton, Hudson, and Leominster, all in Massachusetts, and Schenectady, New York. With the exception of Schenectady, the water supplies of all the communities visited were very soft, i.e., less than 40 mg/l of hardness.

The raw sewage was brought to the laboratory and immediately subjected to analysis and treatment with lime. A 50-liter plastic vat with a settling zone 18 in. deep was used as the treatment vessel. Lime slurry was thoroughly mixed with the sewage to raise the pH to the desired level, usually 11.0 or above. The mixture was slowly stirred for 15 minutes and then

allowed to settle one hour. The supernatant was siphoned off leaving approximately 1.5 liters of supernatant and sludge.

A parallel batch of equal volume was similarly treated with lime. After the period of slow mixing, carbon dioxide was bubbled through the mixture to reduce the pH to 9.5. The slow mixing was continued for an additional 15 minute period followed by one hour's settling. The supernatant of this "recarbonated" sewage was similarly siphoned off.

The sewage, before and after treatment, was analyzed for ammonia and organic nitrogen, ortho- and complex phosphates and organic phosphorus, BOD, and coliform bacteria. The alkalinity and pH were also measured. The procedures of Standard Methods (1) were used for all analyses, with the exception that the stannous chloride used in the phosphate determinations was dissolved in glycerol (2). Organic phosphorus was measured as the difference between ortho plus complex phosphates and total phosphorus as measured by a dry-ash procedure. Several analyses were also made to determine what reduction, if any, of molybdenum and ABS were accomplished by lime treatment.

The sludge volume was measured after standing 24 hours. The filterability of a 200-ml sample of the settled sludge was measured in a 12-cm. diameter Buchner funnel under a vacuum of 20 in. The resulting sludge cake was checked for putrescibility by placing it in an airtight container and noting the odor after a few days.

The two treated sewages were fed to bench-scale continuous-flow activated sludge units which were operated in parallel. The units were seeded with activated sludge developed in raw sewage. It was possible to operate the units with detention periods of 2, 3, 4, and 6 hours. The effluents were analyzed for all forms of nitrogen and phosphorus and for BOD. Alkalinity and pH measurements were also made as well as periodic microscopic examinations of the sludge.

Model stabilization ponds were made out of 1-liter aspirator bottles lying on their sides and fitted with rubber stoppers and drain tubes. The feed was added once daily forcing effluent to overflow through the drain. Artificial illumination of 100-200 ft. candles was supplied during normal working hours.

The stabilization pond models were initially filled with distilled water seeded with a mixed algae culture. The ponds were fed lime treated sewage with and without recarbonation and were operated as detention period of 14 and 45 days. The effluents were analysed weekly for total phosphorus and less regularly for ortho-phosphates and alkalinity. The pH of the effluents varied diurnally. Frequent microscopic examinations of the effluents were also made.

RESULTS

The total phosphorus content and the alkalinity of the six sewages analyzed during the study are given in Table I.

Table I. Total Phosphorus and Alkalinity of Raw Sewages

Source	Total P, mg/L	Range, Total P	Alkalinity
Boston	3.7	1.2-11.3	98
Marlborough	11.5	6.5-17.5	257
Clinton*	5.2	-	75
Hudson*	13.0	-	125
Leominster*	5.8	-	90
Schenectady*	8.7	-	315

*Based on single sample

Since pH measurement would be the most practical means of controlling the lime dosage, preliminary studies were made with the various sewages to determine the optimum pH for phosphorus removal. Typical results are shown on Fig. 1. For weak sewages with low alkalinity, it was necessary to raise the pH above 10.5 in order to get good floc formation and satisfactory settling. Sewages with higher alkalinities usually produced satisfactory flocs at pH levels of 10 or above. Some additional phosphorus removal was accomplished by raising the pH to 11.0 with these sewages, however. It was found that raising the pH above 11.0 did not result in much additional removal. Proportionately much greater amounts of lime were required to raise the pH to levels above 11.0 and this resulted in CaCO_3 turbidity. It is felt that, in practice, preliminary analyses would be necessary to determine the optimum pH. For this study, pH 11.0 was established as the basis for evaluating the lime treatment process.

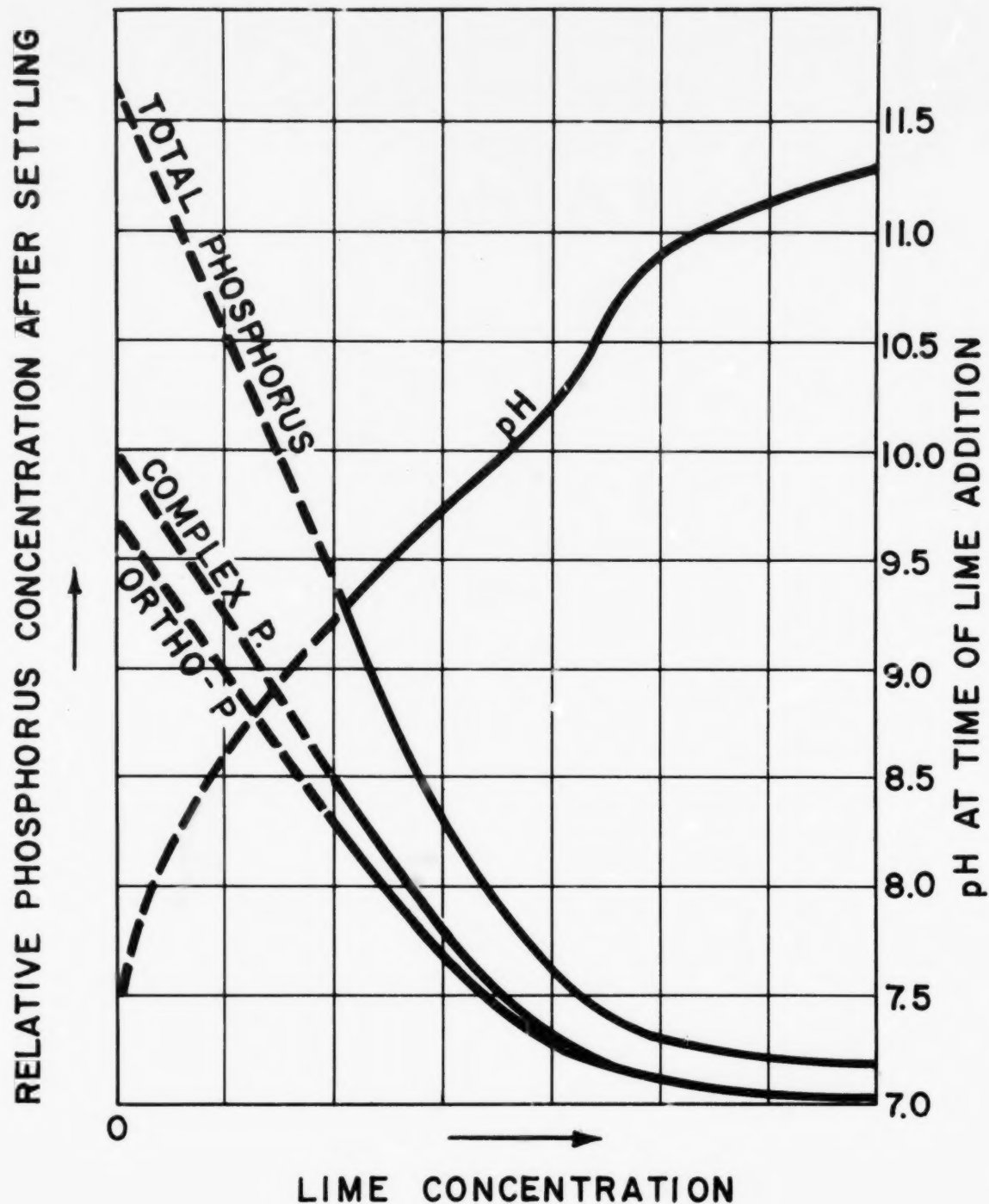


FIG. I
TYPICAL RELATIONSHIP BETWEEN
PHOSPHORUS CONCENTRATION AND
pH WITH INCREASING LIME CONTENT

A brief study was made to determine the amount of lime necessary to raise the pH to 11.0. As would be predicted from a knowledge of water softening chemistry, the lime requirement can be predicted in terms of the alkalinity. It is independent of the phosphorus content, except to the degree that the phosphorus content and the alkalinity tend to vary directly in sewage from a given source. Fig. 2 shows the relationship between the lime requirement and alkalinity.

The supernatant liquid after lime treatment is normally clear and sparkling. Any turbidity present probably indicates improper lime dosage. In some cases color is more noticeable after lime treatment.

Phosphorus. The average phosphorus contents of the Boston and Marlborough sewages before and after treatment with lime alone and with recarbonation are shown on Table II.

Recarbonation of the lime treated sewage significantly decreased the efficiency of phosphorus removal. The purpose of recarbonation was to relieve the saturated lime condition and reduce CaCO_3 aggregation in the activated sludge units.

Nitrogen. The average total nitrogen contents of the raw sewages were: Boston 19.2 mg/L, and Marlboro, 71.0/L. The average percent reductions accomplished by lime treatment are given in Table III.

BOD. The average BOD of the Boston sewage was 100 and of the Marlborough sewage was 237. The BOD data for the sewages after lime treatment are given in Table IV.

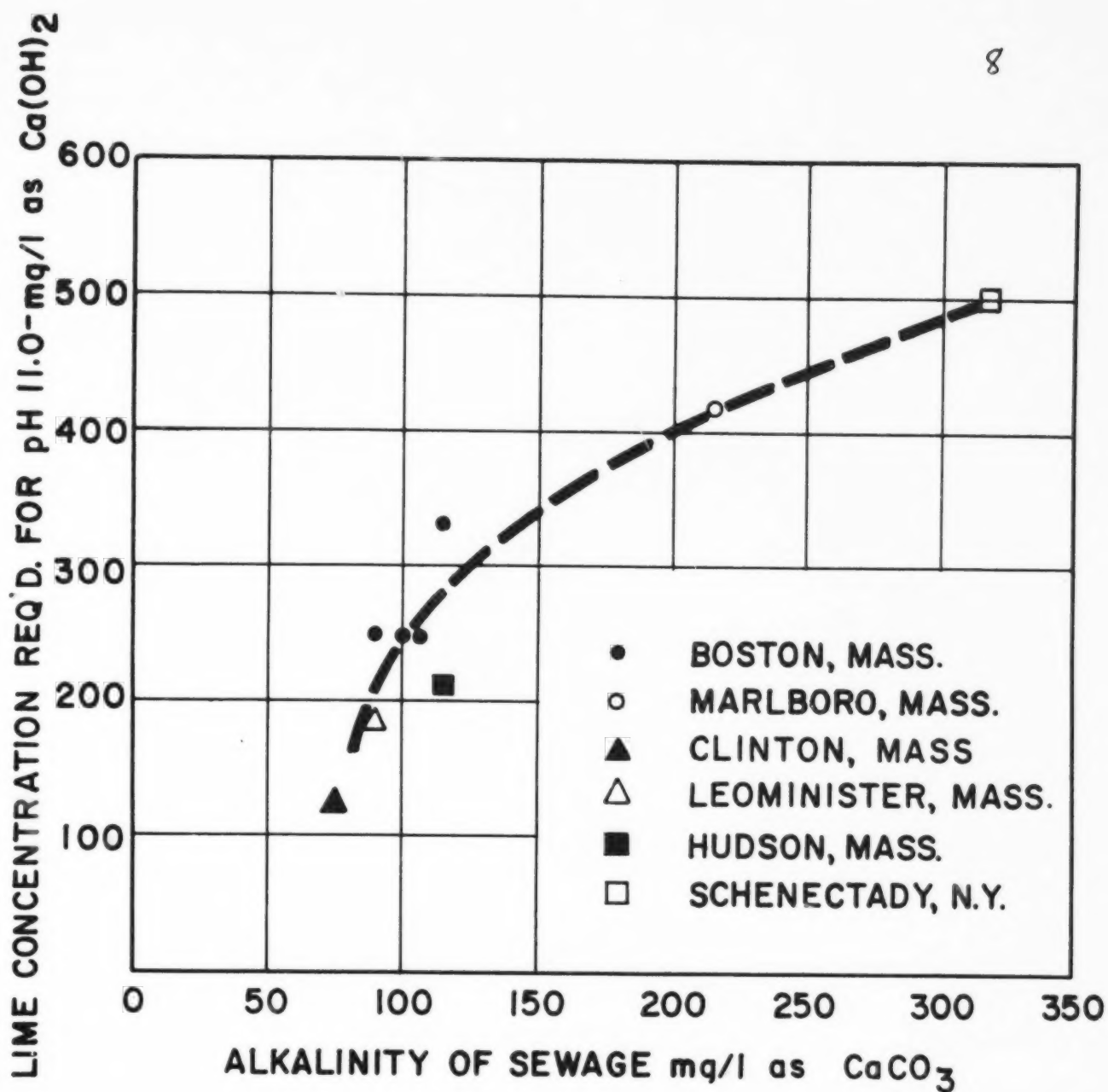


FIG. 2
LIME REQUIREMENTS VS. ALKALINITY
FOR SEVERAL SEWAGES

Table II. Average Phosphorus Content in Sewage
and Reduction with Lime Treatment

	Boston				Marlborough			
	Avg., mg/L	Range, mg/L	V*, mg/L	Reduction, %	Avg., mg/L	Range, mg/L	V*, mg/L	Reduction, %
Raw Sewage								
Inorganic P	2.59	1.0- 60	-	-	8.0	4.1-13.5	-	-
Organic P	1.13	0.2- 6.1	-	-	3.5	2.2- 4.5	-	-
Total P	3.72	1.2-11.3	-	-	11.5	6.5-17.5	-	-
Lime treated sewage								
Inorganic P	0.04	0.02-0.28	0.05	97.5	0.13	0.03-0.37	0.11	98.5
Organic P	0.33	0.09-1.33	0.31	62.0	1.86	0.74-3.83	1.9	47.0
Total P	0.37	0.14-1.45	0.41	90.7	1.99	0.80-4.15	2.0	83.8
Lime treated with recarb.								
Inorganic P	0.28	0.14-0.53	0.31	86.8	0.59	0.42-0.85	0.59	92.2
Organic P	0.20	0.06-1.08	0.21	69.2	2.01	1.17-3.60	2.16	41.0
Total P	0.48	0.23-1.48	0.51	82.8	2.60	1.60-4.45	2.75	77.7

*Two-thirds of the results were equal to
or less than the figure in column V.

Table III. Average Reduction of Nitrogen in Sewage with Lime Treatment

	Boston, %	Marlborough, %
Lime treated sewage	11	
Ammonia nitrogen	11.0	14.3
Organic nitrogen	36.3	43.4
Total nitrogen	23.4	24.4
Lime treated with recarb.		
Ammonia nitrogen	10.2	0.0
Organic nitrogen	35.0	35.4
Total nitrogen	21.8	12.1

Table IV. Average BOD of Sewages and Reduction with Lime Treatment

	Boston		Marlborough	
	BOD	Reduct., %	BOD	Reduct., %
Raw sewage	100	-	237	-
Lime treated sewage	44	56.0	69	71.0
Lime treated with recarb.	45	55.0	77	67.5

Coliform Bacteria. The destruction of coliform organisms depended upon the pH level and the period of contact. The results reported here are all based on a pH of 10.9 or above and a period of contact of one hour. The multiple tube technique was replaced by the membrane filter procedure so that larger volumes of the alkaline liquid could be tested. The destruction of coliforms under the above described conditions was measured 20 times during the course of the study. The "kill" was always greater than 99 percent with a median value of 99.97 percent.

Molybdenum. Several analyses were made to determine the degree of molybdenum removal with lime treatment using plain raw sewage and sewage fortified with small concentrations of molybdenum. It was found that reduction of this important trace nutrient averaged about 20 percent.

ABS. There was no measureable reduction in the concentration of ABS accomplished by lime treatment of sewage.

Nutrient Ratios. The nutrient ratios of the sewages before and after lime treatment are given in Table V.

Table V. Nutrient Ratios of Sewages Before and After Lime Treatment

	BOD/N	BOD/P	N/P
Boston sewage			
Raw	4.8	31	6.3
Lime treated	2.6	140	48
Lime treated with recarb.	2.5	99	31
Marlborough sewage			
Raw	3.4	21	6.4
Lime treated	1.3	39	33
Lime treated with recarb.	1.3	31	25

Sludge. The sludge resulting from the lime treatment was allowed to stand 24 hours and measured volumetrically. There was little difference between the results from the Boston and the Marlborough sewages. The range in volume of sludge was from 0.4 to 2.1 percent with a median value of 1 percent. The volume of the sludge employing recarbonation was typically only 70-75 percent of the volume of sludge from lime treated sewage. The solids content of the sludge ranged between 1.0 and 1.5 percent.

In the filterability tests, a 200-ml sample yielded 100 ml of liquid in between 2.5 and five minutes. The time required to "break the vacuum" ranged from 5 to 15 minutes. The filtering character of the sludge was quite variable from sample to sample. No studies of sludge conditioning to improve the filterability were made.

The putrescibility studies were of a preliminary nature only. It was found that after 4 to 7 days in an air-tight container, sludges with a pH below 11.0 became strongly odorous, indicating decay, while the odor of sludges with pH above 11.0 remained unchanged.

Activated Sludge. The activated sludge units did not function satisfactorily because of the low BOD of the sewage after lime treatment. The growth of organic matter in the sludge was not uniform and regulation of the aeration solids was not always possible. The unit receiving recarbonated influent operated more normally than the unit receiving lime treated sewage. In this latter unit there was an accumulation of CaCO_3 which caused the sludge to be very heavy and difficult to maintain in suspension. The higher BOD of the Marlborough sewage after treatment resulted in better operation of the activated sludge units during that period of the study.

The removals of phosphorus and BOD in the activated sludge units are given in Table VI. There was no removal of nitrogen in the units, although the recarbonated sewage was completely nitrified during its passage through the activated sludge process.

Table VI. Average Reduction of Phosphorus and
BOD in the Model Activated Sludge Units

	P, %	BOD, %
Boston sewage		
Lime treated	48.3	69.5
Lime treated with recarb.	35.0	63.1
Marlborough sewage		
Lime treated	20.5	77.1
Lime treated with recarb.	21.3	74.9

The degree of removal of the two algae nutrients of concern can be interpreted in light of the nutrient ratios. Nitrogen was present in great excess and essentially no removal was accomplished. Greenberg et al (4) found that a BOD/P ratio of about 240 would be necessary for complete phosphorus utilization in activated sludge.

Stabilization Ponds. The N/P ratio for algae growth is in the neighborhood of 30 and since lime treatment of sewage results in ratios in this range and above, stabilization ponds should be well suited as secondary units to strip out the remaining phosphorus. The studies with the model ponds verified this hypothesis. The results are given in Table VII.

Table VII. Median Phosphorus Content and Reduction in
Lime Treated Sewage with Stabilization Ponds

Source	Det. Period	Feed*	Total Phosphorus		
			Content - mg/L Infl.	Effl.	Removal %
A Boston	45 days	L-T	0.23	0.06	73.9
B Boston	45 days	L-T-R	0.43	0.07	84.2
C Marlborough	45 days	L-T	0.80	0.10	87.5
D Marlborough	45 days	L-T-R	1.50	0.10	93.3
E Marlborough	14 days	L-T	0.80	0.33	58.8
F Marlborough	14 days	L-T-R	.150	0.57	62.0

*L-T Lime treated sewage

L-T-R Lime treated with recarbonation

The stabilization ponds reduced the alkalinity of the lime treated sewage to values below 50 and the pH varied diurnally between 8.0 and 10.0. There was never any inorganic phosphorus found in effluents. The reduction in efficiency at 14 days indicates that this detention period is too short.

Within the units most of the algae settled to the bottom side of the bottles. The 45-day ponds produced effluents almost free of algae. The effluents from the 14-day units were quite turbid with green algae cells. The mixed culture used to seed the units developed into nearly pure growths of Scenedesmus.

CONCLUSIONS

1. Lime treatment of raw sewage can effect an 80-90 percent removal of total phosphorus with a better than 97 percent removable of soluble inorganic forms.

2. Lime treatment of raw sewage can remove 50-70 percent of the BOD, almost 25 percent of the nitrogen, and 99.9 percent of the coliform bacteria.

3. The lime requirement is independent of the phosphorus content and can be predicted in terms of the alkalinity. Lime dosage can be controlled by pH measurement. For each situation the optimum pH should be determined.

4. The volume of sludge produced in lime treatment is approximately 1 percent of the volume of sewage treated. Chemical conditioning may be necessary to improve the filterability of the sludge in some cases. Further studies are necessary to determine whether or not the sludge would be suitable for agricultural lands.

5. The activated sludge process does not provide a very suitable secondary treatment step because of the low BOD in the lime treated sewage.

6. Lime treatment of sewage produces effluents with N/P ratios of 30 or above. This is significant in two ways:

- a. If discharged directly, this material should not stimulate the growth of blue-green algae which often flourish in nitrogen-poor environment; and
- b. Stabilization ponds should provide very suitable secondary treatment.

7. Polishing of the lime treated sewage in stabilization ponds removed 75-80 percent of the remaining phosphorus.

8. Lime treatment of sewage for algae control appears to be very worthy of further study and pilot-plant investigation.

ACKNOWLEDGEMENTS

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